INTEGRATED AGRICULTURAL SYSTEMS

Tillage and Compost Affect Yield of Corn, Soybean, and Wheat and Soil Fertility

J. W. Singer,* K. A. Kohler, M. Liebman, T. L. Richard, C. A. Cambardella, and D. D. Buhler

ABSTRACT

Applying organic matter (OM) amendments to cropland reduces requirements for synthetic fertilizer and may eliminate yield differences between conventional and minimum tillage. The objectives of this research were to determine how tillage and composted swine (*Sus scrofa* L.) manure affected yield of corn (*Zea mays* L.), soybean [*Glycine max* (L.) Merr], and wheat (*Triticum aestivum* L.) and soil concentrations of OM, P, and K. A corn–soybean–wheat/clover (*Trifolium* spp.) rotation, in all phases, was initiated in 1998 in plots that had been managed with moldboard plow (MP), chisel plow, or no-till since 1988. Moldboard and chisel plow increased corn yield in the first year of the study vs. no-till. Thereafter, tillage did not affect yield on plots that received compost. Tillage × compost interactions during the last 2 yr of the study increased no-till compost yield 11% vs. no compost. Soybean yield was similar in no-till and chisel compost plots during the study period and between MP and no-till in 3 of 4 yr. Tillage × compost interactions were observed in 2 of 4 yr that increased no-till compost yield 9% vs. no compost. Averaged across all crops and tillage, compost-amended soil had 63 g kg^{-1} OM and 164 mg kg^{-1} P vs. 56 and 55 in no compost. Corn and soybean producers can enhance yield with multiple compost applications and eliminate yield differences between conventional and no-till systems. Nevertheless, compost application for soil OM enhancement must be balanced with P input to minimize the potential for excessive soil P accumulation.

Recent data from the Conservation Technology Information Center (CTIC) indicate that no-till corn acreage in the Midwest has not increased in recent years. Land area in no-till corn in 2000 was 17% compared with 18% in 2002 (CTIC, 2002). Corn producers are reluctant to use no-till in corn production because of inconsistent yields compared with intermediate or intensive tillage systems (Erbach, 1982; Kaspar et al., 1987). Kaspar et al. (1990) recommended removing a 16-cm band of residue from the row area to increase corn stand and hasten emergence. Nevertheless, reports in the literature present inconsistent results comparing modified no-till (using row cleaners) to conventional tillage systems.

Environmental concerns from soil erosion are rivaled by concerns about nutrient loading. Increased on-site nutrient loading from concentrated animal feeding operations (CAFOs) have prompted investigations into alternative uses for manure produced in various livestock management systems. Because manure handling in modern dairy (*Bos taurus*) and swine production systems is usually in a liquid or slurry form, hauling costs to distribute this dilute manure from large CAFOs can be prohibitive. Compost, which has a lower water content than fresh manure, can provide more cost-effective transport of manure-derived nutrients to cropland off-site of CAFOs or other large-scale livestock facilities (Richard and Choi, 1999). A new swine management housing system uses hoop structures (Honeyman et al., 2001) in which solid manure is mixed with corn stalks or grain straw bedding materials. Opportunities exist to haul this nutrient and C source to reduce on-site loading. Bosch and Napit (1992) concluded that off-site transfer of poultry litter, which averaged 465 g kg^{-1} water, was economically viable but was adversely affected by transportation costs. They reported profitable transfer of poultry litter from surplus to deficit areas up to 81 km.

Utilizing composting to manage nutrient inputs for crop production presents certain challenges. Surface compost application may not be as efficient as incorporation because of additional N loss or nutrient stratification. Eghball (2000) reported that 11% of the organic N that was applied the previous fall was mineralized from composted beef cattle feedlot manure and that N mineralization was similar in no-till and conventional tillage even though the compost was surface-applied in no-till. Eghball and Power (1999a) in Nebraska reported similar dryland corn grain yields in no-till and conventional tillage (disking and cultivation) with beef feedlot compost in 3 of 4 yr. In the fourth year, no-till yielded less than conventional tillage with compost application. Compost application rates were similar in both tillage systems and were selected to provide 151 kg N ha^{-1} in their continuous corn study. They concluded that surface application of beef feedlot manure or composted manure did not result in significant N loss. Other studies have reported different N requirements for no-till vs. conventional tillage. Stecker et al. (1995) found that no-till corn following soybean on poorly drained claypan soils required 17 kg ha^{-1} more fertilizer N than a chisel-disk system for maximum corn yield and 45 kg ha^{-1} more N for maximum profit.

Applying OM amendments to soil increases soil fer-

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Abbreviations: CAFOs, concentrated animal feeding operations; LSNT, late-spring soil NO_3–N; MP, moldboard plow; OM, organic matter.

tility. Eghball (2002) reported that after 4 yr of N- or P-based manure and compost applications, soil surface C and N concentrations and quantities were greater in the N- compared with the P-based management systems. Eghball and Power (1999b) found that P- or N-based compost or manure application resulted in similar corn grain yield, but the P-based systems had significantly less soil available P after 4 yr of application. The objectives of the present research were to determine how tillage and compost affected yield of corn, soybean, and wheat and soil concentrations of OM, P, and K.

MATERIALS AND METHODS

Field research was conducted at the Iowa State University Agronomy and Agricultural Engineering Research Farm near Boone, IA (42°01′ N, 93°45′ W), from 1999 through 2002 on Canisteo silty clay loam (fine-loamy, mixed, superactive, calcareous, mesic Typic Endoaquolls) and Clarion loam (fine-loamy, mixed, superactive, mesic Typic Hapludolls) soils. The experimental site had been in continuous corn production since 1987, with tillage main plots consisting of MP, chisel plow, and no-till since 1988. In 1997, the entire site was planted to soybean. Soil samples collected from the top 18 cm in 1997 indicated that tillage had not affected soil pH (6.7), OM (63 g kg^{-1}), P (Bray-1, 54 mg kg^{-1}), or K (ammonium acetate extraction, 210 mg kg^{-1}) levels. Organic matter concentrations were determined by dry combustion (Nelson and Sommers, 1996) using a LECO CHN-2000 (LECO Corp., St. Joseph, MI). In 1998, a corn–soybean–wheat/clover rotation was initiated with all phases represented each year (Table 1) in each tillage system.

The experimental design was a randomized complete block in a split-plot arrangement of treatments with four replications. Tillage main plots, 22.8 m wide by 13.1 m long, were fall MP, fall chisel plow, and no-till. Moldboard plow depth was approximately 20 cm. Chisel plow depth was 25 cm using twisted shanks. A John Deere 7000 no-till planter was used with Sukup row cleaners (Sukup Manufacturing Co., Sheffield, IA). Spring secondary tillage operations included an early spring disking and a preplant field cultivation in MP and chisel plow systems. Rotary hoeing and interrow cultivation were performed as needed in corn and soybean crops each year in all tillage systems.

Subplots, 7.6 m (10 rows with a 76-cm row spacing) wide by 13.1 m long, consisted of the application of bedded swine manure compost (amended) or no compost. Compost application rate during the first crop rotation cycle (1998–2000) was set at 8000 kg C ha^{-1} per application and reduced to 4000 kg C ha^{-1} thereafter. Compost rates to achieve the C application target were 61.6, 74.7, 54.1, and 22.3 Mg dry matter ha^{-1} in 1998, 1999, 2000, and 2001, respectively (Table 2). Additionally, in 1998, 1999, 2000, and 2001, the straw residue after wheat harvest was allowed to remain on the compost plots but was removed from the no-compost plots. Compost was applied using a John Deere 45 manure spreader to appropriate subplots in all tillage systems. The fall MP and chisel plow operations were conducted within 3 d after compost application.

Table 1. Crop sequence and compost application.

1996	1997	1998	1999	2000	2001	2002
Cont. corn	soybean	wheat/cl†‡	corn‡	soybean	wheat/cl‡	corn
Cont. corn	soybean	soybean	wheat/cl‡	corn‡	soybean	wheat/cl
Cont. corn	soybean	corn‡	soybean	wheat/cl‡	corn‡	soybean

† cl = berseem clover in 1998 and 1999 and red clover in 2000 and 2001.
‡ Compost application.

Table 2. Compost application rate and N, P, and K applications from 1998–2001.

Year	Compost	N	P	K
	dry Mg ha^{-1}	kg ha^{-1}		
1998	61.6	653	–	–
1999	74.7	568	374	837
2000	54.1	703	390	871
2001	22.3	310	138	306

All of the compost was produced on the Iowa State University Rhodes Research Farm in Marshall County, IA, except for the compost used in October 1998, which was produced from similar hoop structures on a commercial farm in Story County, IA. Compost was applied after corn and wheat in the crop rotation (Table 1). Compost properties for each year are listed in Table 3. Compost total C and N were determined after acidification with 0.5 *M* HCl (1:2 sample/solution ratio), air drying, grinding, and dry combustion in a Carlo-Erba NA1500 NCS elemental analyzer (Haake Buchler Instruments, Paterson, NJ) as described by Cambardella et al. (2003). Total P and K were determined on dried ground samples after digestion with 10 mL of deionized water, 5 mL of HNO_3, and 1 mL of HCl. Potassium was analyzed using atomic absorption in emission mode while P was determined colorimetrically using ascorbic acid/ammonium molybdate. Compost moisture content was determined by drying at 70°C for 48 h. Eight soil cores to a depth of 18 cm were collected each spring in each subplot to monitor changes in P, K, and OM concentrations.

Corn (‘Pioneer Brand 3563’) was planted in late April of each year at a seeding rate of 81 510 seeds ha^{-1}. Starter fertilizer was not applied. Late-spring soil NO_3–N (LSNT) concentrations were used to determine sidedress N application rates in compost and no-compost plots. In 1999, 2001, and 2002, rates were averaged across tillage systems. In 2000, six rates were applied based on means for each tillage by compost combination. Eight to 10 soil cores from the surface 30 cm were collected on 7 June 1999, 30 May 2000, 4 June 2001, and 5 June 2002, from each subplot, and a composite sample was processed (Blackmer et al., 1989). In 1999, 2001, and 2002, 151, 174, and 123 kg N ha^{-1} were applied to no-compost plots, and 118, 151, and 67 kg N ha^{-1} were applied to compost plots. In 2000, 162, 106, and 106 kg N ha^{-1} were applied to the no-compost plots in no-till, chisel plow, and MP systems, respectively, while the compost plots received 146, 84, and 62 kg N ha^{-1} for the three tillage systems. All sidedress N was 32% urea ammonium nitrate (UAN) applied using a point-injector applicator. Twelve stalk samples (20 cm in length) were collected 15 cm above the soil surface at grain harvest, dried at 60°C for 5 d, ground to pass a 0.85-mm screen, and analyzed for NO_3–N by leaching 0.25 g of the ground sample with 50 mL of 2 *M* KCl solution, creating a 200-fold dilution. Nitrate N concentration in the leachate was determined using a Lachat autoanalyzer (Method 12-107-04-1-B, Lachat Instruments, Milwaukee, WI).

Table 3. Composition of fall 1998–2001 compost amendment.

Year	H_2O†	P	K	C	N	C/N	NH_4–N	NO_3–N
	g kg^{-1}						μg g^{-1}	
1998	340	–	–	114	10.6	10.8	–	–
1999	318	5.0	11.2	105	7.6	13.8	84	63
2000	311	7.2	16.1	147	13.0	11.3	339	999
2001	415	6.2	13.7	227	13.9	16.3	103	396

† Moisture content is presented on a wet weight basis; all other variables are presented on a dry weight basis.

Table 4. Mean air temperature and monthly cumulative precipitation, Boone, IA, from 1999–2002.

	1999		2000		2001		2002		Long-term avg.†	
Month	Air temp.	Precip.	Air temp.	Precip.	Air temp.	Precip.	Air temp.	Precip.	Air temp.	Precip.
	°C	mm	°C	mm	°C	mm	°C	mm	°C	mm
April	9.6	189	10.1	26	11.8	88	9.1	86	9.7	88
May	15.9	146	17.5	116	16.0	164	14.3	112	16.2	110
June	20.7	171	19.9	109	21.0	47	22.6	71	21.2	129
July	25.2	146	22.3	73	24.2	42	24.4	134	23.3	102
August	21.3	144	22.8	31	22.6	67	21.4	124	22.0	105
September	15.9	60	18.5	25	16.3	135	18.7	32	17.6	81

† Long-term avg. = 1951–1999.

Soybean (‘Pioneer Brand 9294’) was planted in mid-May in all years at a rate of 444 600 seeds ha^{-1} in 76-cm rows. No fertilizer was applied during the soybean phase of the crop rotation. Wheat (‘Arapahoe’) was drilled in early October of each fall at a rate of 3.2 million seeds ha^{-1} in 19-cm rows. Oat (*Avena sativa* L.) was seeded in the spring of 2001 because of severe winterkill in the wheat crop. ‘Bigbee’ berseem clover (*Trifolium alexandrinum* L.) was frost-seeded in March of 1998 and 1999 while ‘Cherokee’ red clover (*Trifolium pratense* L.) was frost-seeded in March of 2000 and 2001 at a rate of 20 kg seeds ha^{-1} using a drop spreader. Ammonium nitrate fertilizer was topdressed in the wheat annually in early April at a rate of 45 kg N ha^{-1}. Clover was chemically killed each fall. Typical management practices were used for corn and soybean weed control. No herbicide was applied to wheat. All crops were harvested with a plot combine. Three interior corn and soybean rows were harvested after end-trimming. Reported grain yields are adjusted to a moisture content of 155, 130, and 130 g kg^{-1} for corn, soybean, and wheat, respectively.

Analysis of variance (ANOVA) was conducted using the PROC MIXED routine of SAS (SAS Inst., 2000) to test for main and interaction effects. A separate model was used each year for yield, LSNT, and stalk nitrate. Organic matter, P, and K data from 2002 were examined using data from 1999 as a covariate and analyzed as a split-split plot design with tillage, rotation, and compost as factors. Block and all block-related terms were considered random. All analyses were guided by procedures presented in Littell et al. (1996). Different variance-stabilizing transformations were used for each analysis. Least-square means for each factor along with selected contrasts were also estimated. Regular and spatial residual diagnostics were examined to see if the error assumptions were reasonably met. All results were considered significant if P values were ≤ 0.05.

RESULTS AND DISCUSSION

Temperature and precipitation data for 1999 through 2002 are presented in Table 4. Most notable were variations in precipitation in 1999 when above-average precipitation occurred from April through August. In 2000, below-average precipitation was recorded in April and June through September. In 2001, below-average precipitation occurred from June through August.

Corn

Corn yields are presented in Table 5. In 1999, tillage affected corn yields, with MP and chisel yielding 10 and 16% greater than no-till, respectively. No difference was observed between MP and chisel. Compost and the tillage × compost interaction were not significant in 1999. In 2000, compost increased corn yield 6% compared with no compost. Tillage and the tillage × compost interaction were not significant in 2000. In 2001, tillage, compost, and the tillage × compost interaction were significant. No difference was detected between MP with or without compost, but chisel with compost

Table 5. Tillage and compost effects on corn and soybean grain yield near Boone, IA, from 1999–2002.

	Corn				Soybean			
Variable	1999	2000	2001	2002	1999	2000	2001	2002
	Mg ha^{-1}							
Moldboard plow (MP)	11.1†	10.6	11.7	12.7	3.9†	3.9	3.6	4.2
Chisel	11.9	10.4	11.0	12.0	3.6	3.7	3.5	4.1
No-till	10.0	10.7	10.7	12.0	3.8	3.5	3.5	4.0
Compost	10.9	10.9	11.4	12.5	3.7	3.7	3.7	4.2
No compost	10.9	10.2	10.8	11.9	3.7	3.6	3.3	4.0
Tillage × compost								
MP-compost	10.8	10.6	11.7	12.7	3.7	3.9	3.7	4.4
MP-no compost	11.3	10.6	11.7	12.7	4.0	3.8	3.4	4.1
Chisel-compost	11.9	10.6	11.3	12.0	3.5	3.7	3.7	4.1
Chisel-no compost	11.9	10.1	10.6	11.9	3.6	3.7	3.2	4.0
No-till-compost	10.2	11.6	11.1	12.8	3.9	3.6	3.8	4.2
No-till-no compost	9.7	9.8	10.2	11.2	3.6	3.3	3.2	3.8
	$P > F$							
Analysis of variance								
Tillage	0.0043	0.7857	0.0391	0.2182	0.1413	0.0002	0.5240	0.1614
Compost	0.8853	0.0468	0.0027	0.0501	0.6530	0.0003	0.0001	0.0001
Tillage × compost	0.3517	0.1525	0.0462	0.0521	0.2646	0.0433	0.5046	0.0001
Contrasts								
MP vs. chisel	0.1101	0.5672	0.0746	0.1299	0.0579	0.0197	0.2851	0.2400
Chisel vs. no-till	0.0014	0.5436	0.3208	0.9784	0.1595	0.0011	0.4002	0.4079
No-till vs. MP	0.0175	0.9713	0.0145	0.1360	0.5880	0.0001	0.8137	0.0648

† Statistical analysis performed on 1/yield transformed data.

yielded 6% greater than without compost, and no-till with compost yielded 8% greater than without compost. No yield differences were observed among all tillage systems with compost. In 2002, tillage did not affect yield, but compost and a tillage × compost interaction were detected. No difference was observed between MP or chisel with or without compost, but no-till with compost yielded 13% greater than without compost. No difference was detected among all tillage systems with compost. The tillage × compost interaction may be partially explained by N management.

Nitrogen application was based on the LSNT (Table 6). Tillage, compost, and the tillage × compost interaction for LSNT were significant in 1999. No difference in LSNT was detected between MP with or without compost (10.0 vs. 8.7 mg kg^{-1}) while chisel and no-till with compost (12.4 and 11.8 mg kg^{-1}) had higher LSNT than without compost (8.4 and 6.4 mg kg^{-1}, data not presented). In 2000, tillage and compost affected the LSNT. No difference was detected between MP and chisel tillage, but both tillage systems had higher LSNT values than no-till. Compost increased the LSNT value by 27% compared with no compost. In 2001, tillage did not affect LSNT values, but adding compost increased the LSNT 25% compared with the no-compost treatment. Tillage and compost were significant in 2002. Moldboard plow had 24% higher LSNT values than no-till. And adding compost increased the LSNT 21% compared with the no-compost treatments. Except for 2000, N application using the LSNT was determined by averaging the LSNT across tillage to achieve a single rate for compost and no-compost plots. This approach to determine an N application rate favored MP and provided a disadvantage to no-till, assuming N-limited yield. In 2000, although different N rates were applied for each tillage by compost or no-compost plot (six rates), tillage did not affect corn grain yield.

The explanation for the interaction between tillage and compost for grain yield may not be simply related to N. All plots were frost-seeded with clover during the wheat phase of the crop rotation before corn production. Bruulsema and Christie (1987) reported that red clover undersown to an oat crop provided the equivalent of 147 kg N ha^{-1} to a subsequent corn crop. Nitrogen application in addition to berseem or red clover in the compost and no-compost plots probably contributed adequate N, such that N limitation may not be a reasonable explanation for the tillage × compost interaction.

The fall stalk nitrate data generally suggest that N limitation may not be responsible for the tillage × compost interaction. Stalk nitrate concentrations between 250 and 1800 mg kg^{-1} indicate adequate inorganic soil N for maximum grain yield (Binford et al., 1990). All of the fall stalk nitrate concentrations fell within this range (Table 7), except for chisel plow plots that did not receive compost in 2001. The yield of chisel plow with compost was 6% greater than without compost in 2001. In 1999, corn plants from plots that received compost had 1726 mg kg^{-1} greater stalk nitrate concentrations than plants from plots that did not receive compost, but no difference in grain yield was detected from compost application. In 2000, tillage increased stalk nitrate concentrations in MP and no-till compared with chisel, but tillage did not affect grain yield. No tillage or compost effect was detected in 2002. Other explanations for yield differences may include soil water-holding capacity. Hudson (1994) reported that available water capacity of soil more than doubles as OM content increases from 5 to 30 g kg^{-1}. In 2000, the driest year during our study period, when July and August precipitation were 28 and 70% below the long-term average, corn yield in no-till and chisel plow with compost exceeded no-compost plots although no yield difference was detected between compost and no-compost plots in MP. Organic matter concentrations were not affected by tillage, and averaged across tillage, OM content in compost plots was 61 g kg^{-1} compared with 57 g kg^{-1} in the no-compost plots (data not presented). This 7% difference may have increased water infiltration in no-till and chisel tillage but may not have altered available water content in MP. In 2001, June, July, and August precipitation were 64, 59, and 36% below average, respectively, and a similar response was observed to 2000. In 2001, averaged across tillage, differences in OM increased to 11% between compost and no-compost plots (data not presented).

Table 6. Tillage and compost effects on late-spring soil NO_3–N near Boone, IA, from 1999–2002.

Variable	Soil NO_3–N 1999	2000	2001	2002
	mg kg^{-1}			
Moldboard plow (MP)	9.4†	14.0	7.8	13.8
Chisel	10.4	12.5	6.0	11.9
No-till	9.1	7.7	5.5	10.5
Compost	11.3	11.3	7.3	13.5
No compost	7.7	8.3	5.5	10.7
	$P > F$			
Analysis of variance				
Tillage	0.0558	0.0011	0.1123	0.0236
Compost	0.0001	0.0221	0.0212	0.0044
Tillage × compost	0.0054	0.6001	0.8486	0.5239
Contrasts				
MP vs. chisel	0.2230	0.4433	0.1238	0.1207
Chisel vs. no-till	0.0197	0.0035	0.5618	0.1621
No-till vs. MP	0.1523	0.0009	0.0485	0.0023

† Statistical analysis performed on 1/√ transformed data.

Table 7. Tillage and compost effects on fall stalk NO_3–N near Boone, IA, from 1999–2002.

Variable	Stalk NO_3–N 1999	2000	2001	2002
	mg kg^{-1}			
Moldboard plow (MP)	902†	1240	831	385
Chisel	1384	520	233	582
No-till	1216	1911	401	294
Compost	2182	1230	735	540
No compost	456	763	244	302
	$P > F$			
Analysis of variance				
Tillage	0.7159	0.0125	0.1397	0.6156
Compost	0.0001	0.0941	0.0049	0.2159
Tillage × compost	0.0654	0.9412	0.4356	0.5364
Contrasts				
MP vs. chisel	0.4413	0.0230	0.0648	0.5381
Chisel vs. no-till	0.5983	0.0027	0.3992	0.3505
No-till vs. MP	0.5983	0.1097	0.1685	0.7316

† Statistical analysis performed on √ transformed data.

Table 8. Tillage, rotation, and compost effects on soil organic matter (OM), P, and K concentrations from the 0- to 18-cm soil depth, near Boone, IA, in 2002.

Variable	Corn			Soybean			Wheat		
	OM†	P‡	K§	OM	P	K	OM	P	K
	g kg^{-1}	mg kg^{-1}		g kg^{-1}	mg kg^{-1}		g kg^{-1}	mg kg^{-1}	
Moldboard plow (MP)	60	88	208	56	109	220	57	90	175
Chisel	58	91	159	60	122	178	56	97	189
No-till	64	104	200	61	113	189	60	108	199
Compost	65	141	218	63	178	248	60	173	281
No compost	56	57	162	56	65	153	56	44	125
	$P > F$								
Analysis of variance									
Tillage	0.0437	0.6537	0.2893	0.0437	0.6537	0.2893	0.0437	0.6537	0.2893
Rotation	0.2117	0.2521	0.8730	0.2117	0.2521	0.8730	0.2117	0.2521	0.8730
Tillage × rotation	0.4970	0.9612	0.4625	0.4970	0.9612	0.4625	0.4970	0.9612	0.4625
Compost	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Tillage × compost	0.0605	0.0997	0.1869	0.0605	0.0997	0.1869	0.0605	0.0997	0.1869
Rotation × compost	0.3604	0.2259	0.0216	0.3604	0.2259	0.0216	0.3604	0.2259	0.0216
Tillage × rotation × compost	0.1608	0.3057	0.2812	0.1608	0.3057	0.2812	0.1608	0.3057	0.2812
Contrasts									
MP vs. chisel	0.6801	0.5610	0.1715	0.6801	0.5610	0.1715	0.6801	0.5610	0.1715
No-till vs. chisel	0.0506	0.7048	0.1783	0.0506	0.7048	0.1783	0.0506	0.7048	0.1783
No-till vs. MP	0.0196	0.3646	0.7953	0.0196	0.3646	0.7953	0.0196	0.3646	0.7953

† Statistical analysis conducted on 1/√ transformed data.
‡ Statistical analysis conducted on √ transformed data.
§ Statistical analysis conducted on log-transformed data.

Soybean

Soybean yields are presented in Table 5. In 1999, no effect of tillage or compost was detected. In 2000, tillage and compost were significant, and a tillage × compost interaction was observed. Soybean yields in MP and chisel with or without compost were similar, but no-till with compost yielded 8% greater than without compost. Moldboard plow with compost produced higher yields than either chisel or no-till with compost while MP and chisel had similar yields without compost, and both were greater than no-till without compost. In 2001, averaged across tillage, yields from plots with compost were 11% greater than from plots that did not receive compost. In 2002, tillage did not influence grain yields, but compost and a tillage × compost interaction were significant. Similar yields were obtained with MP or no-till with compost, but chisel plow with compost yielded 7% less than MP with compost. Compost addition did not affect grain yield in chisel plow, but MP and no-till with compost yielded 7 and 10% greater than no compost.

In a Wisconsin study (Kurle et al., 2001), no-till and chisel plow produced similar soybean yields and on average yielded 11% greater than MP. In our study, tillage affected yield in 2 of 4 yr with MP = chisel > no-till without compost. The increase in soybean yield in 2000, 2001, and 2002 with compost could be attributable to more favorable plant N status from N mineralization because recent studies have presented inconsistent soybean yield responses from in-season N application (Wesley et al., 1998; Freeborn et al., 2001; Schmitt et al., 2001). Although soil P was greater in plots that received compost (Table 8), Borges and Mallarino (2000) reported that no-till soybean yield did not respond to soil test P levels greater than 9 mg P kg^{-1} from the 0- to 15-cm soil depth. Compost and no-compost plots exceeded this level, so differences in soil P probably do not account for the yield differences we observed in no-till between compost and no-compost plots. The results of Borges and Mallarino (2000) also suggest that differences in K probably do not account for the yield differences we observed in no-till. They reported small yield responses to K at only 5 of 20 long-term sites where soil K was optimum or higher according to current interpretations for tilled soils, as was the case at the present site (Table 8).

Wheat

Tillage did not affect wheat yield during the study period (Table 9). Compost comparisons were not possible in 1999 because no compost was applied to wheat plots in the fall of 1998 (Table 1). In 2000, compost increased yield 7% compared with no compost. Although compost effects were not statistically significant in 2001 and 2002, compost increased yield numerically by 5 and 4% compared with no compost. Unlike corn and soybean, no tillage × compost interaction was observed for wheat yield.

Table 9. Wheat yield near Boone, IA, from 1999–2002.

Variable	1999†	2000	2001‡	2002
	Mg ha^{-1}			
Moldboard plow (MP)	3.6§	4.5	4.2	5.5
Chisel	3.7	4.5	4.4	5.4
No-till	3.6	4.4	4.3	5.6
Compost	–	4.6	4.4	5.6
No compost	–	4.3	4.2	5.4
	$P > F$			
Analysis of variance§				
Tillage	0.8051	0.6940	0.5470	0.6395
Compost	–	0.0358	0.1095	0.1083
Tillage × compost	–	0.7235	0.6553	0.2656
Contrasts				
MP vs. chisel	0.7281	0.8326	0.2966	0.6192
Chisel vs. no-till	0.5280	0.4150	0.4315	0.3546
No-till vs. MP	0.7705	0.5439	0.7908	0.6587

† No compost had been applied to wheat plots.
‡ Oat was planted in the spring of 2001 because of wheat winterkill.
§ Statistical analysis was conducted on 1/yield transformed data.

Soil Organic Matter

Organic matter concentrations were not affected by tillage ($P = 0.9260$) before the establishment of the crop rotation in 1998. Organic matter levels in MP, chisel plow, and no-till were 65, 64, and 62 g kg^{-1} at the end of the previous study. During the course of the present study, tillage affected OM concentrations (Table 8). Averaged across crop rotation, no-till had 6% greater OM concentrations than MP and chisel plow. No difference was detected between MP and chisel. Application of compost had the greatest effect on OM in all phases of the rotation. Similar differences were observed in corn, soybean, and wheat with (63 g kg^{-1}) and without (56 g kg^{-1}) compost. Corn production in 1999 and 2000 occurred on plots that had only received one compost application. In 2001, corn was produced on plots that received two compost applications while in 2002, corn plots received three compost applications. Compost plots had 13% higher OM concentrations compared with no-compost plots after both two (2001) and three (2002) compost applications (data not presented). Soybean was produced in 1999, 2000, 2001, and 2002 following one, two, two, and three compost applications, respectively. Wheat produced in 1999, 2000, 2001 (oat), and 2002 followed zero, one, two, and two compost applications, respectively. Regardless of the different number of compost applications to the different plots, main effect of rotation or any of the interactions were significant.

Soil Phosphorus

Soil P (54 mg kg^{-1}) concentrations were high before the establishment of the crop rotation in 1998 and were unaffected by tillage system. Additions of P from fall compost applications in 1999, 2000, and 2001 were 374, 390, and 138 kg P ha^{-1}. Tillage and tillage interactions were not significant for soil P (Table 8). Rotation and rotation interactions also were not significant. Ishaq et al. (2001) reported that wheat removed from 12.3 to 16.2 kg P ha^{-1} in different tillage and fertilizer rate combinations. The relatively low P removal rates in wheat, the crop that preceded corn in the rotation, in addition to the high P additions from compost did not affect soil P concentrations in the different crop phases. Eghball and Power (1999b) added an average of 128 and 32 kg P ha^{-1} annually using N- and P-based compost application. These P additions were dramatically lower than our C-based compost application and only supplied 7945 and 3916 kg C ha^{-1} for the N- and P-based systems during their 4-yr study, which was 72 and 86% less C than in our 4 yr study. In their study, the average total corn P uptake was similar for N- and P-based compost application (33 kg P ha^{-1}). Averaged across crops and tillage, compost application increased soil P to 164 mg kg^{-1} compared with 55 mg kg^{-1} without compost.

Soil Potassium

Soil K (210 mg kg^{-1}) was similar across tillage systems before the establishment of the crop rotation in 1998. Compost-derived K inputs were 837, 871, and 306 kg K ha^{-1} in 1999, 2000, and 2001, respectively (Table 2). Compost application in 1998, 1999, and 2000 was 61.6, 74.7, and 54.1 Mg ha^{-1}, respectively. In the fall of 2001, 22.3 Mg ha^{-1} was applied because the C-based compost rate was reduced after the first 3-yr cycle from 8000 to 4000 kg C ha^{-1} per application. Compost and a rotation $\times$ compost interaction were significant for soil K (Table 8). Compost application increased soil K 26, 38, and 55% compared with no compost in the corn, soybean, and wheat phases, respectively. No differences were observed among K concentrations in the corn, soybean, or wheat phases with compost, but with no compost, plots in corn were 23% higher than plots in wheat. This difference may be explained by higher yields in the corn and soybean phases of the rotation that removed more soil K than the corn plots, which were preceded by wheat.

CONCLUSIONS

Amending soil with composted swine manure can increase corn and soybean yields, but no difference was observed after only one compost application. Moldboard plow and chisel plow only increased corn yield in the first year of the study compared with no-till. Thereafter, no differences in tillage for corn yield occurred on plots that received compost. Tillage $\times$ compost interactions for yield during the last 2 yr of the study increased no-till corn yield with compost compared with no compost. Although specific causes for this set of responses are not apparent, our data suggest that N was not responsible for the yield increase in no-till corn. Soybean yield was similar in no-till and chisel plow on compost plots during the entire study period and between MP and no-till in 3 of 4 yr. A tillage $\times$ compost interaction was observed for soybean yield in 2 of 4 yr that increased no-till yield with compost compared with no compost. It is unclear if N contributed to the yield increase in no-till soybean because reports in the literature present inconsistent data on soybean yield response to in-season N application. It is possible that nutrient uptake alone may not be responsible for the yield responses we observed, but uptake efficiency from improved soil physical, chemical, and biological properties may interact to increase yield in crops produced on compost-amended soil. Corn and soybean producers can enhance yield with multiple swine compost applications and eliminate yield differences between conventional and no-till systems. Nevertheless, compost application for C enhancement must be balanced with associated P inputs to minimize the potential for excessive P accumulation.

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